Drop Size Distribution from Medium–Sized Agricultural Sprinklers

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THE drop size distribution of sprinkler spray is of practical importance for two reasons. First, the small droplets are subject to wind drift, distorting the application pattern. Second, large droplets possess greater kinetic energy which is transferred to the soil surface causing particle dislodgement and puddling that may result in surface crusting and runoff.

The drop size distributions from medium-size agricultural sprinklers were measured to study the effects of pressure and nozzle size on the distributions. These are two parameters that farmers can change on existing systems to cope with field problems caused by low intake rates and runoff.

METHODS

Droplet size was measured by the flour method similar to that used by Laws and Parsons (1943). Circular pans 21 cm in diameter and 2 cm deep were filled with fresh, bleached wheat flour by sifting and carefully struck off with a straight edge. The pans of flour were never allowed to stand more than 2 hr before exposure to the sprinkler spray. After exposure, the pans of flour were dried for 24 hr at 38 C. An 18.3 cm diameter sample was taken from the center of the pans to avoid droplets that might have been cut by the sharp edge of the pan. This sample was placed on a 50 mesh sieve and shaken on a reciprocating shaker to separate the dough balls from the flour. The dough balls were separated by sieving using a set of 16 sieves of U.S. series 5 to 50 mesh sieve sizes and weighed.

The mass ratio (R), water droplet mass to dry flour pellet mass (M_p), was determined by dropping droplets of known mass into flour pans from various heights. Distance of fall from 0.1 to 4 m appeared to have no effect on R. The values of R for droplet sizes of 2.19 to 5.32 mm diameter were the same as those obtained by Meyer (1958). Therefore, Meyer's equation was used for the entire size range,

$$R = 1.05\,M_p^{0.062}.$$

An impact type agricultural sprinkler* was allowed to rotate and distribute its spray over the pans of flour. Three pans were placed on arcs at 2 m intervals to the outer limit of the spray. The nozzle was located 0.75 m above the pan surface. On the first rotation only the spoon spray was sampled; pans were shielded from the main jet. On the next rotation, only the jet was sampled. This is possible because the spoon spray exits the sprinkler at an angle to the main jet. Sample pans were supported above the floor to avoid splash. Rates of sprinkler rotation and discharge were measured.

To obtain the total spray distribution, the samples collected at 2 m intervals were weighed according to the area of the sprinkler pattern they represented and summed in a manner similar to that of Inoue (1963).

SPRINKLER JET BREAKUP

The relatively high pressures used in sprinkler irrigation result in sufficiently high jet velocities for jet disintegration to occur in the secondary atomization region as defined by Ohnesorge and modified by Miesse (1955). In this region, inertial, viscous and capillary forces are significant in the jet disintegration. However, the complicated nature of the breakup process defies rigorous theoretical analysis. Attempts at correlating dimensionless groups, usually those containing inertial, viscous and surface tension forces along with a group relating a representative drop diameter to nozzle diameter, have met with some success. However, the value of these correlations in predicting or designing sprinkler jet breakup remains to be demonstrated.

A jet of water issuing from a nozzle into the atmosphere eventually breaks into droplets because its initial form is disturbed. The shear of the air against the water surface is not sufficient in itself to disturb the surface of the jet and cause breakup. Turbulent eddies in the water column, no longer having a rigid boundary after emergence from the nozzle, cause the jet surface to deviate and break away from the main stream. Rouse et al. (1952) have aptly described the ensuing breakup. "It is only after the surface of the jet has become sufficiently disrupted to produce an appreciable form resistance that the action of the air begins. Such resistance is roughly proportional to the square of the water velocity and to the cross-sectional area of the expanding jet. Thus, as ever more eddies carry water laterally out of the central stream, they are rapidly retarded in their longitudinal course by the surrounding air, but they continue to spread laterally at only slightly diminished speed. Although the outermost fringes of the jet at once form droplets that fall as a spray, the central portion appears simply to disintegrate in midair. In other words, since the equal and opposite reaction to the retardation of the water is the acceleration of the surrounding air, the originally intact but turbulent jet is transformed along its trajectory into an expanding mixture of dispersed water drops and air that travels at an ever-decreasing speed but brings an ever-increasing volume of air into motion."

Water deviating from the jet surface will encounter air at a greater differential velocity than water globules disintegrating near the jet axis where air has been entrained. Merrington and Richardson (1947) have shown that the mean diameter of drops formed from jet breakup is inversely dependent on the jet's *relative* velocity to the surrounding

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Article was submitted for publication in December 1973; reviewed and approved for publication by the Soil and Water Division of ASAE in May 1974.

Contribution from the Agricultural Research Service, Western Region, USDA; University of Idaho College of Agriculture Research and Extension Center, Kimberly, cooperating.

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*Nelson F32 and F33 sprinklers with quick change nozzles were used. Mention of trade products or companies in this paper does not imply that they are recommended or endorsed by the Department of Agriculture over similar products of other companies not mentioned. Trade names are used here for convenience in reference only.

Trans ASAE 17(4):690-693, July-Aug 1974

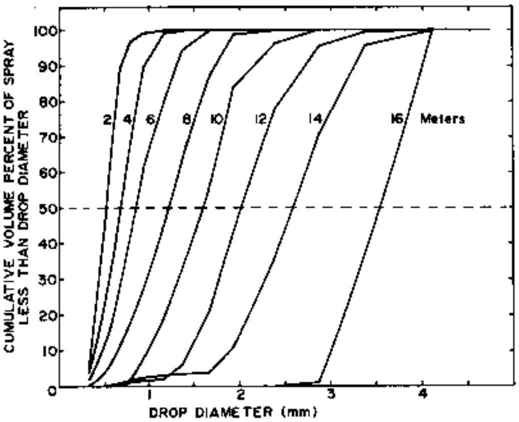

FIG. 1 The drop size distributions collected at 2 meter intervals from the main jet of a 5/32 in. (3.97 mm) nozzle operated at 40 N/cm² (58 psi) pressure.

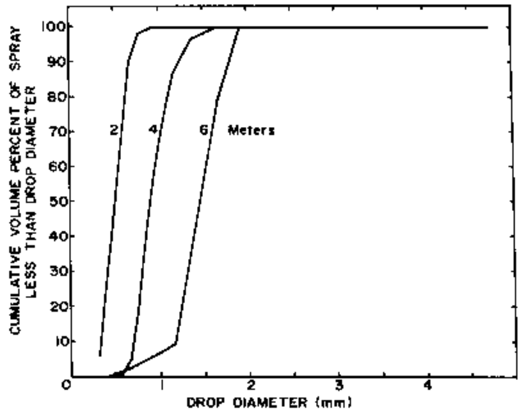

FIG. 2 The drop size distributions collected at 2 meter intervals from the spoon of a sprinkler with a 5/32 in. (3.97 mm) nozzle operated at 40 N/cm² (58 psi) pressure.

air. Therefore, water near the periphery of the jet will result in small droplets while the water near the core of the jet with the lowest *relative* velocity to the air will produce the largest droplets.

At each location along the disintegrating jet a distribution of droplet sizes is produced. Also, since the speed of the smaller droplets decreases more rapidly than larger droplets, the mean size of drops falling closer to the nozzle will be much smaller than that of drops collected further from the nozzle. This effect is illustrated in Fig. 1 where the drop size distributions at 2 m intervals from the main jet are presented. The volume mean diameter for a drop size distribution is the drop diameter above and below which half of the volume of discharge occurs. The volume mean diameters of the distributions in Fig. 1 occur at the intersection of the horizontal line through 50 percent on the ordinate and the lines representing the distributions at a given distance.

The drop size distributions for the mechanical breakup from the sprinkler spoon are presented in Fig. 2 for comparison only.

DROP SIZE DISTRIBUTION VS. PRESSURE AND NOZZLE SIZE

Fig. 3 illustrates the effect of pressure on the drop size distribution from a 5/32 in. (3.97 mm) nozzle. The vertical axis represents the discharge, ΔQ, per mm of drop diameter, ΔD, to produce an area under the bar graph proprotional to the sprinkler discharge in cm³/sec. As pressure was increased, the volume of water applied as larger droplets decreased while there was a large increase in the volume applied as smaller droplets to make up the larger total discharge. Since jet velocity is proprotional to the water pressure in the supply line, the higher pressures should produce greater relative velocities between the water and the air, resulting in a larger number of smaller droplets. The data obtained and plotted in Fig. 3 substantiate this.

The effect of nozzle size on the drop size distribution was smaller than that of pressure, as illustrated in Fig. 4 where drop size distributions for three nozzle sizes operated at 40 N/cm² pressure are presented. The volume of water applied as larger droplet sizes increased with increasing nozzle diameter. Under the same nozzle approach conditions, a small diameter jet will tend to separate and air will be entrained through to its center more rapidly than will a jet of

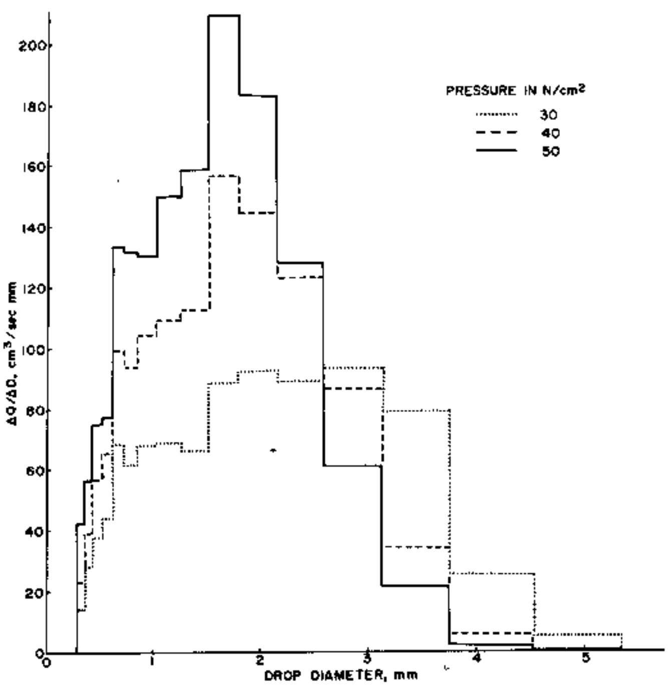

FIG. 3 The drop size distributions from a 5/32 in. (3.97 mm) diameter nozzle operated at 3 pressures.

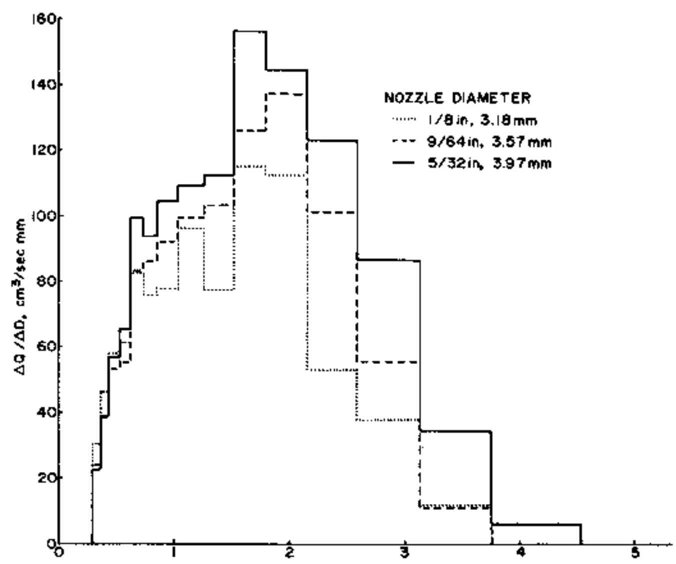

FIG. 4 The drop size distributions from 3 nozzles operated at 40 N/cm² (58 psi) pressure.

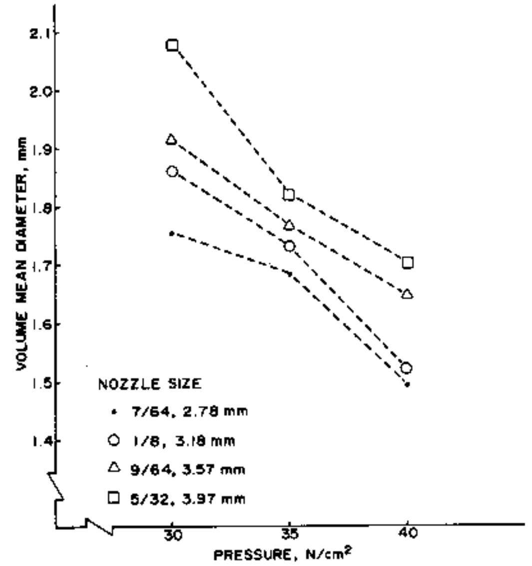

FIG. 5 The volume mean diameter of the drop size distribution as a function of sprinkler pressure for different nozzle sizes.

larger diameter. This process will result in larger relative velocity differences between water and air in smaller jets. The larger relative velocity and smaller water globules breaking up result in smaller water droplets from the smaller nozzles.

The relative importance of water pressure and nozzle diameter on the volume mean diameter of the total spray distributions is illustrated in Fig. 5. While the smaller nozzles produce a smaller mean drop size, operating a small nozzle at low pressure can produce mean drop sizes larger than larger nozzles operating with higher pressure.

KINETIC ENERGY

The kinetic energy of the spray as it reaches the land surface was calculated for the measured drop size distributions using the velocities at impact elevation listed in Table 1. The data of Schladerbusch and Czeratsky (1957) were used for velocities of droplets less than 2.5 mm in diameter and the method of Seginer (1965) was used to calculate the velocities of larger droplets.

The kinetic energy values presented in Fig. 6 represent the energy resulting from an application of 1 mm depth of water to 1 sq m of surface. Again the effect of both nozzle size and pressure are evident. Schleusener and Kidder (1960), using lower pressures (24 and 28 N/cm^2), also found a decrease in energy applied to a strain gage target with an increase in pressure. However, they found a decrease in applied energy with an increase in nozzle size (5/32 to 3/16 in., 3.97 to 4.76 mm) while holding pressure constant which appears contrary to the results of this study. Since a larger nozzle in a sprinkler normally causes the sprinkler to rotate faster the larger nozzle would have applied water to the target for less time during the single pass and, therefore, less energy would have been recorded with the larger nozzle.

However, when considering both duration of application (time) and dis-

TABLE 1. DROP VELOCITIES AT IMPACT ELEVATION USED TO CALCULATE THE KINETIC ENERGY OF THE DROP SIZE DISTRIBUTIONS.

Drop diameter, mm	Impact velocity, m/s	Drop diameter, mm	Impact velocity, m/s
0.33	1.33	1.37	4.33
0.39	1.60	1.66	4.89
0.49	2.03	1.93	5.27
0.57	2.25	2.39	5.93
0.67	2.54	2.88	6.50
0.78	2.89	3.38	6.83
0.93	3.29	4.12	7.12
1.16	3.92	4.93	7.26

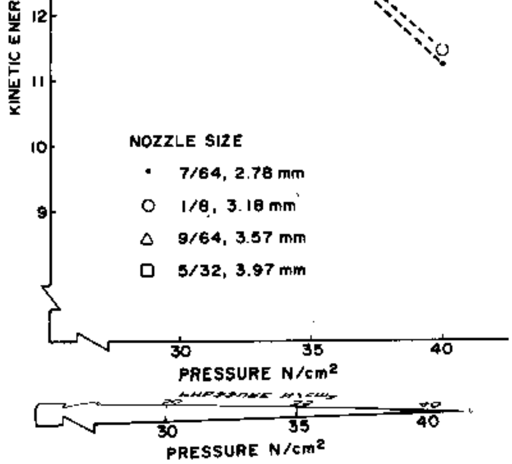

FIG. 6 The kinetic energy of the drop size distributions for an application of 1 mm depth of water to 1 sq m (10^{-3} m^3, 1 liter) as a function of nozzle

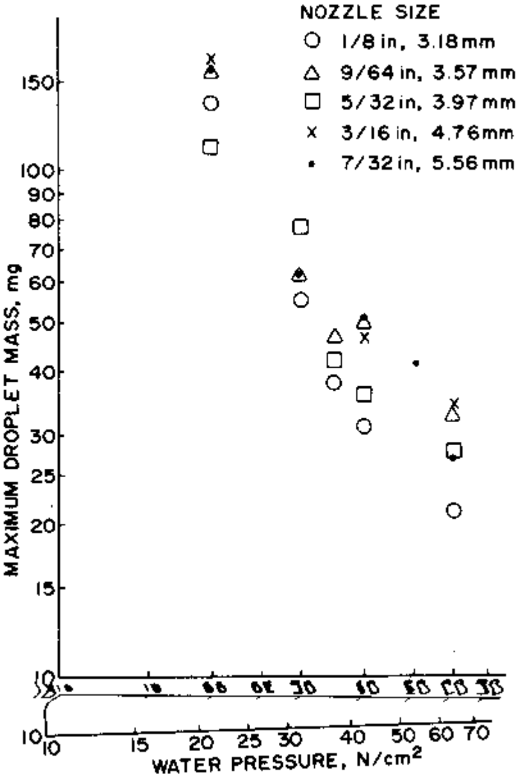

FIG. 7 The maximum droplet mass produced by various nozzle sizes operating at different pressures.

charge, all nozzle sizes and pressures considered were evaluated per unit of water applied in this study as illustrated in Fig. 6. It is evident that when applying equal amounts of water to a field, the kinetic energy can be reduced by using smaller nozzles or increasing pressure.

The kinetic energy of sprinkler spray is important where erosion and surface crusting, the latter reducing soil infiltration rates, are problems. Young and Wiersma (1973) found that an 89 percent reduction of rainfall energy, without reduced water application rate, decreased total soil loss from their research plots by 90 to 94 percent depending on soil type. Since the largest droplet sizes have the highest velocities at ground level, and because kinetic energy is a product of droplet mass and its velocity squared, the maximum droplet sizes transfer much more kinetic energy to the soil surface than small droplets. Levine (1952) found a very large increase in aggregate breakdown with increasing drop size which emphasizes the importance of the largest droplets.

The effect of nozzle size and pressure on the maximum droplet mass is presented in Fig. 7. While the maximum droplet mass is similar over a rather large range in nozzle sizes, it is very sensitive to water pressure. Maintaining adequate sprinkler pressure when irrigating soils with crusting problems appears to be an important management factor in minimizing soil crusting.

SUMMARY

The drop size distributions from agricultural sprinklers followed the relationship of decreasing drop size with increasing relative velocity of the water to the air. Decreasing nozzle diameter decreased mean drop size, but increasing pressure decreases mean drop size by a greater amount. The kinetic energy of the spray at the soil surface followed the same pattern.

The maximum droplet mass, important on soils with crusting problems, was very sensitive to water pressure. It increased fivefold with a pressure decrease from 60 to 20 N/cm^3 (87 to 29 psi).

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